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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

for

Diagnostics of Severe Convection and
Subsynoptic Scale Ageostrophic Circulations

Contract NAS 8-33222

For the Period of

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Diagnostics of Severe Convection and Subsynoptic Scale Ageostrophic Circulations

Introduction

This document constitutes the final report to NASA contract NAS 8-33222 for research work conducted on "Diagnostics of Severe Convection and Subsynoptic Scale Ageostrophic Circulations." The work was initiated on 1 June 1979 and completed on 14 September 1984. The research supported under NASA contract was to study mesoscale circulations through forcing of ageostrophic motion by adiabatic, diabatic and frictional processes. The efforts included theoretical and diagnostic work and the development and application of a hybrid isentropic sigma coordinate numerical model. The numerical model simulated mesoscale ageostrophic circulations associated with propagating jet streaks and severe convection. The following is a complete list of publications and theses completed through support of the NASA severe storms research project.

Keyser, D. A. 1981: Effects of diabatic heating on the ageostrophic circulation of an upper tropospheric jet streak. M.S. Thesis, University of Wisconsin-Madison, 121 pp.

Keyser, D. A., and D. R. Johnson, 1983: Effects of diabatic heating on the ageostrophic circulation of an upper tropospheric jet streak. NASA Contractor Rep. 3497 (1982), prepared for Marshall Space Flight Center under Contract NASA8-33222, [NTIS 8216658], 121 pp.

Schlesinger, R. E., L.W. Uccellini, and D. R. Johnson, 1983: The effects of the Asselin time filter on numerical solutions to the linearized shallow-water wave equations. Mon. Wea. Rev., 111, 455-467.

Johnson, D. R., and L. W. Uccellini, 1983: A comparison of methods for computing the sigma coordinate pressure gradient force for flow over sloped terrain in a hybrid theta-sigma model. Mon. Wea. Rev., 111, 870-886.

Keyser, D. A., and D. R. Johnson, 1984: Effects of diabatic heating on the ageostrophic circulation of an upper tropospheric jet streak. Mon. Wea. Rev., 112, 1709-1724.

Johnson, D. R., 1984: The inducement of planetary boundary layer mass convergence associated with varying vorticity beneath tropospheric wind maximum. Presented at Nowcasting II, The Second International Symposium on Nowcasting, Norrköping, Sweden, September 3-7, 1984. Published in Proceedings of the Second International Symposium on Nowcasting, Norrköping, Sweden by the European Space Agency. (ESA SP-208), 41-46.

Black, T. L., 1984: Numerical experiments of jet streak ageostrophic circulations using pseudo-geostrophic initialization and perspectives. Ph.D. Thesis, University of Wisconsin-Madison, 185 pp.

Abstracts for each of the publications which summarize the key findings of each study in Appendix A are included. All of the results presented in these papers are addressed to the research objectives for which support was provided. Copies of the publications have been forwarded previously.

Summary of Results

A key finding of the diagnostic case study of severe weather by Keyser and Johnson (1983) using the AVE IV data set was that the diabatic ageostrophic motion associated with the isallobaric component and vertical advection of momentum are important in explaining the transverse circulations of a jet streak in its entrance region, the intensification of the downstream jet streak and the production of kinetic energy in the jet streak itself. Generation of kinetic energy occurs through diabatically forced vertical advection of momentum that induces within the entrance region horizontal ageostrophic motion towards lower pressure. This result provides the physical basis to establish how thermal convection can force the generation of organized kinetic energy within vertically sheared larger scale flow. This result was later verified through Black's (1984) numerical experimentation. The study also included an evaluation of quasi- and semi-geostrophic approximation in the study of ageostrophic circulations. All of the approximations to the total motion and advective processes were lacking. The results of this study were published in the Monthly Weather Review (see abstract and paper for details of the results.)

The work by Schlesinger, Uccellini and Johnson (1983) studied the numerical properties of differencing schemes in order to separate physical and computational modes associated with advection and viscous diffusion in our hybrid isentropic sigma coordinate model. This study was conducted to emphasize the proper selection of viscosity for given resolution in time and space.

The work by Johnson and Uccellini (1983) establishes the ability of the hybrid model to undertake numerical simulations of mesoscale circulation in the vicinity of sloped terrain. Serious truncation errors are introduced in all numerical simulations of flow over elevated terrain with a principle error being associated with the pressure gradient force. In this experiment, several different finite difference forms to calculate the pressure gradient force were compared through use of a suggestion by Phillips (1974). Our development of a conservative finite difference form for the pressure gradient force shows that the truncation error is reduced and that realistic mesoscale circulations in the vicinity of elevated terrain can be predicted with this model. Such work was essential in order to be able to accurately simulate mesoscale circulation and severe weather in regions of mountainous terrain.

The work by Johnson (1984) (and Panetta, a post doc supported by the contract) was initiated to understand how the depth of the planetary boundary layer and frictionally induced cross isobaric flow is modified by the vorticity distribution of frontal structures and jet streak phenomena. In the theoretical part of this work, nonlinear advective processes in conjunction

with the viscous effects of an Ekman layer were included to establish that the vertical distribution of vorticity is one of the primary parameters that determines the Ekman mass transport from high to low pressure within the planetary boundary layer. The viscous forces in the boundary layer beneath the anticyclonic side (negative relative vorticity) to the right of a jet streak core will tend to induce stronger mass transport from the anticyclonic to the cyclonic side (positive relative vorticity) of the jet streak than the viscous forces in the boundary layer beneath the cyclonic side of the jet streak. The combination of these results indicate that the maximum systematic mass convergence within the planetary boundary layer will occur directly beneath and immediately to the right of the jet core. The preliminary results from the case study in this paper supported this conclusion. A rule used by many forecasters for severe weather prediction is that the severe weather develops beneath the 500 mb zero isobaric relative vorticity isopleth (Rosenthal, 1979). The theoretical results support this forecasting rule since the region of maximum vertical wind shear in a baroclinic atmosphere constitutes the region of maximum lateral gradient of relative vorticity on an isentropic surface. Thus, this region becomes the likely locus for the development of severe weather.

A key part of the research effort was devoted to model development of an isentropic-sigma coordinate model used to study the ageostrophic circulations of propagating baroclinic jet streaks. In this effort it was necessary to recode the Uccellini, Johnson and Schlesinger (1979) model. This model development effort addressed six points: 1) increase of resolution, 2) simplification of logic, 3) improved accuracy of truncated grid volumes immediately above the interface of the isentropic sigma coordinate domain, 4) improved accuracy of pressure gradient computations for truncated volumes, 5) addition of water vapor continuity equation and 6) inclusion of viscous forces whereby conservation of momentum was insured for isentropic, sigma and truncated isentropic domains of the model.

The experiment included studies of initialization using pseudo-geostrophic balance and the effects of vertical shear, horizontal shear, latent heat and friction on the mesoscale circulations.

In a series of experiments, the horizontal wind shear of the jet streak was increased relative to previous experiments while retaining the same maximum wind speed and alongstream variation in the wind. The result was an enhanced development of the direct and indirect circulations at the jet entrance and exit regions, respectively, as revealed by increased precipitation in the jet's left exit region. From quasi-geostrophic concepts, the increase in positive differential vorticity advection enhanced the vertical motion and increased the precipitation. The increase in positive vorticity advection was associated with the larger positive vorticity on the jet's cyclonic side. Another test was made in which the initial anticyclonic wind shear was increased only on the jet's anticyclonic side (reducing the absolute vorticity from 4×10^{-5} to $1.5 \times 10^{-5} \text{ s}^{-1}$) but was not increased on the cyclonic side. Thus, the positive differential vorticity advection was not increased. Precipitation was still 50% greater under the jet's left exit

region than for the original experiment. In this case, the increased ageostrophic response of the baroclinic jet streak and increased upward vertical motion cannot be explained by vorticity advection. It must be explained using Eliassen's concepts in the sense that a decrease in the absolute vorticity results in an enhanced response of the indirect circulation at the jet exit. This in turn leads to greater upward motion on the cyclonic side and thus to increased precipitation.

Another experiment involved decreasing the static stability below the jet streak while maintaining essentially the same velocity structure. This was accomplished by increasing the ground temperature by 10 K along the center of the channel and increasing the lapse rate from $5 \times 10^{-3}\text{ K/m}$ to $6 \times 10^{-3}\text{ K/m}$. Areas of precipitation formed under the right entrance and left exit regions with magnitudes three to four times larger than for the original experiment.

A third experiment involved the superposition of an amplifying baroclinic wave on the jet streak. The maximum wind and alongstream variation of the jet streak at 340 K were nearly the same as in the zonal experiments. In this case, baroclinic instability aided in the development of low and high pressure centers and along cold and warm frontal regions south and east of the low. A relatively continuous band of precipitation developed along the baroclinic zone. Areas of maximum rainfall tend to coincide with the areas of greatest positive thermal advection. The results of these experiments are being prepared for publication.

Recommendations for Future Research

A basic premise of our research work is that the use of isentropic coordinates for theory, analysis and prediction readily links diabatic processes with atmospheric circulation at the mesoscale. In regions where the motion is adiabatic, the transport of physical properties is quasi-horizontal. Diabatic processes induce vertical exchange of atmospheric properties.

In this regard, isentropic assimilation models undoubtedly have the potential of improving water vapor analyses needed for accurate initial conditions for mesoscale prediction. Prior to onset of convection, the distribution of water vapor is constrained to remain within the isentropic layer of its origin and be governed solely by quasi-horizontal transport processes. As such its spatial integrity must be more coherent if analyzed isentropically.

In view of these considerations and the explicit link between vertical advection of properties and diabatic processes in regions of convection, we make several recommendations.

Future work should investigate the strengths and weaknesses of:

- 1) Determination of atmospheric structure from conventional and satellite observations using a time-dependent isentropic assimilation models.

- 2) Tests of numerical mesoscale prediction comparing different methods of analyses from different assimilation models (e.g. sigma versus isentropic).
- 3) Isentropic models for numerical weather prediction.

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